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Drying and Quality Characteristics of Different Components of Alfalfa

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Abstract *This study investigated the effect of air temperature (100°C – 200°C) and velocity (0.15m/s – 0.45m/s) on drying characteristics and quality of different alfalfa components. The chopped alfalfa components, including stems, crushed stems, crushed stems with attached leaves, and leaves were used for the study. The moisture losses under different drying conditions and times were measured. The quality of dried products, including color, protein, and fiber content was also examined. The leaves and uncrushed stems had the highest and lowest drying rates among the four components. The increase of drying temperature and air velocity resulted in higher drying rates of all components. But the increase also caused high difference in moisture contents of leaves and stems of dried stems with attached leaves. The activation energies of stems, crushed stems, crushed stems with attached leaves and leaves were 387.6, 346.6, 411.0, and 606.7 kJ/mol, respectively. Based on the test results, to achieve high drying rate and desirable product quality of alfalfa a combination of 160°C temperature and 0.3m/s air velocity is suggested.*

Keywords. alfalfa, drying temperature, drying rate, quality, modeling.

Introduction

Alfalfa (*Medicago Sative, L.*) is one of the most important forage crops with excellent sources of protein, vitamins and minerals. Typically, after harvest, alfalfa is dried or sun-cured with solar radiation in the field. However, solar dying has disadvantages of long drying time and possible significant nutrient loss of the dried alfalfa. Therefore, mechanical drying has been a great interest in preserving the freshness and nutrients of the dried alfalfa.

It has been reported that field curing loss caused up to 11.2% yield loss and protein became less soluble (Rotz and Abrams, 1988). To produce a high quality and uniform product, harvested alfalfa should be dried to about 10% moisture as fast as possible for storage. Since the alfalfa contains stems and leaves with different physical and chemical characteristics, the stem and leaves have different drying rates and moisture contents in finished product, which could post safety storage problem. Patil et al. (1992) found the leaves and chopped stems with attached leaves had the highest and lowest drying rates, respectively, among leaves, chopped stems and stems with attached leaves at 60°C. The leaves required only 40% of the drying time of 50mm length stems without leaves. Leaves attached to stems required 20% longer drying times than stems alone. To improve the drying rates of stems and whole alfalfa, chopping and crushing have been proved to be the effective methods. The maturity of alfalfa also had significant effect on drying rate. The alfalfa stems cut at 10% bloom stage resulted in a 44% reduction in drying time compared to prebloom samples due to the high moisture content in the prebloom samples.

Drying temperature is one of the most important parameters affecting the drying rate in alfalfa drying. Several reported research works have focused on the effect of drying temperature on drying rate (, Patil et al., 1992). The highest drying temperature without causing charring was 250°C. Patil et al. (1992) studied drying characteristics of leaves, chopped stems and stems with attached leaves in a temperature range from 60°C to 80°C. The results showed that drying rate was significantly improved when the temperature from 60°C to 70°C, but no significant change in drying rate from 70°C to 80°C. The researchers suggested more research to be done to determine the drying behavior of alfalfa at these and higher temperature.

The major quality indictors of alfalfa hay include dry matter (DM), crude protein, neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, calcium (Ca), and phosphorus (P) (Pei, 2001). The nutritional quality of alfalfa hay can be determined based on crude protein and crude fiber which can be used to estimate NDF and NDF. High crude protein and fiber in alfalfa are desirable. However, drying process may affect the nutritional quality and appearance of alfalfa hay. Patil and Sokhansanj (1994, 1998) found that intense heating of alfalfa degraded the plant protein to a degree that it might not be digestible. But reduced temperature may result in moist stems, which can cause concern of safe storage. However, little information is available about the effect of using high temperature drying on the drying and quality characteristics of alfalfa hay.

In this study, the objectives were (1) to determine the drying characteristics of different components of alfalfa hay under high drying temperatures and (2) to study the effect of drying temperature and air velocity on the quality of alfalfa hay.

Materials and Methods

Material preparation

The first cut alfalfa of variety Canada #1 grown on an experimental farm near Northeast Agricultural University in Harbin, China, was used for this study. A mechanical forge harvester was used to harvest the alfalfa when it reached 10% bloom stage. The harvested alfalfa was immediately placed in plastic bags with double layers and tied securely to ensure them airtight. These samples were stored in a freezer at –4°C for about 2-3 days before they were used for the drying tests. Before drying tests, the samples were taken out of the bags, uniformly spread on laboratory floor and kept for 4-6 h to reach equilibrium ambient temperature. The alfalfa was first chopped into 4 cm pieces with a mechanical cutter and then four components were prepared. The uncrushed stems and leaves were obtained by manually separating the leaves from the stems. To obtain the crushed stems and stems with attached leaves (whole alfalfa plant), the chopped alfalfa plants were crushed by using a rubber hammer to achieve uniform crushing. The crushed stems were obtained by further separating the crushed leaves and stems of chopped alfalfa. The moisture contents (MC) of the alfalfa components before and after drying were determined using the air oven method (ASAE standard S358.1, ASAE, 1992) at 103°C for 24 h. The initial moisture contents of crushed stems with attached leaves, crushed stems, un-crushed stems and leaves were 78.32, 73.88, 76.34 and 80.36%, respectively, on the wet basis.

Drying method

A thin layer drying device described by Zheng (2004) was used to conduct the drying studies. The device consisted of heating elements, air blower and drying tray. The temperature of drying air heated by the electrical heating elements was controlled using an automatic controller. To study the effect of drying temperature on drying characteristics of different components of alfalfa, six temperatures, from 100°C to 200°C with increment of 20°C, with air velocity of 0.30 m/s were used. The weight of the sample was measured using an electronic balance during drying. The moisture contents at different drying conditions and times were calculated based on initial moisture contents and sample weights. The drying process was stopped when the final moisture content reached about 12% (w.b.). The average drying rate was calculated as the difference between the initial and final moisture contents divided by the drying time.

Drying modeling

The following exponential model has been used for thin layer drying to describe the drying characteristics of alfalfa drying with satisfactory results (Patil et al., 1992) and was also used for this study.

$$MR = \frac{M - M_e}{M_0 - M_e} = \exp[-kt] \qquad (1)$$

Where:

M_0 = initial moisture content (% d.b.),

M = instantaneous moisture content at time t (% d.b.),

M_e = equilibrium moisture content (% d.b.),

k= drying constant (min^{-1}), and

t= elapsed time (min).

The reported equilibrium moisture contents (EMC) of chopped stems at 60, 70 and 80 C were 5.16, 2.43, and 1.42 kg/kg (d.b.) (Patil et al., 1992). Since the drying temperatures used in this study were much higher than the reported temperatures, the EMCs for different components in this study were assumed as zero. Then the Eq. (1) can be simplified as

$$\frac{M}{M_0} = \exp[-kt] \qquad (2)$$

The drying constant k was determined by fitting the obtained moisture data at each drying temperature against time with Microsoft Excel software. The correlation coefficient (R^2) was examined to determine the wellness of the model fitting.

Since drying constant k is related to drying temperature and its value increases with the increase of drying temperature, the relationship between the drying constant k and drying temperature can be determined by using the Arrhenius Equation (Mujumdar, 2000).

$$k = k_0 \exp(-E_a / RT) \qquad (3)$$

Where k_0 is a constant; Ea is the activation energy (J mol^{-1}); R is the universal gas constant with the value of 8.314 x 10^{-3} kJ /mol·K, and T is the temperature (K). The constant k_0 and activation energy E_a were determined by using regression analysis based on the drying temperatures and corresponding k values for each alfalfa component.

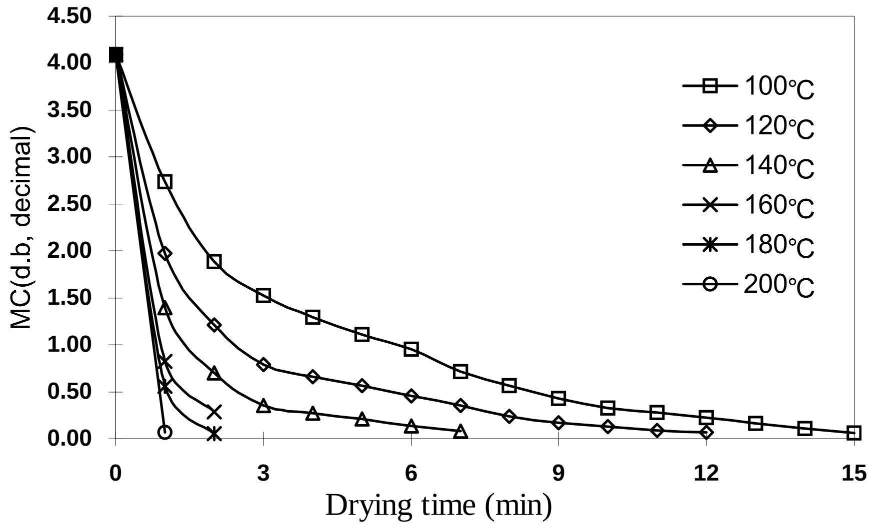
Effect of drying temperature and air velocity

To determine the effect of drying conditions on the moisture content and quality of dried products, crushed stems with attached leaves, crushed stems and leaves were dried to 12% moisture with different temperatures (100C to 200C) under three air velocities (0.15, 0.30, 0.45m/s). To determine the moisture difference between the stems and leaves after the stems with attached leaves were dried, the chopped and crushed stems with attached leaves were dried. The leaves and stems were manually separated after drying and their moisture contents were determined. Crude protein in dried leaves and crude fiber of dried stems were measured by using official analysis methods in triplicates and the average results are reported as dry basis. The crude protein content was calculated by multiplying nitrogen content by 6.25. Since the color of alfalfa hay is another important quality factor, the green colors of alfalfa leaves before and after drying were measured using a color meter (D-65 illuminant 100, Labscan Inc.). The greenness values of dried leaves were reported as percentage of alfalfa leaves before drying.

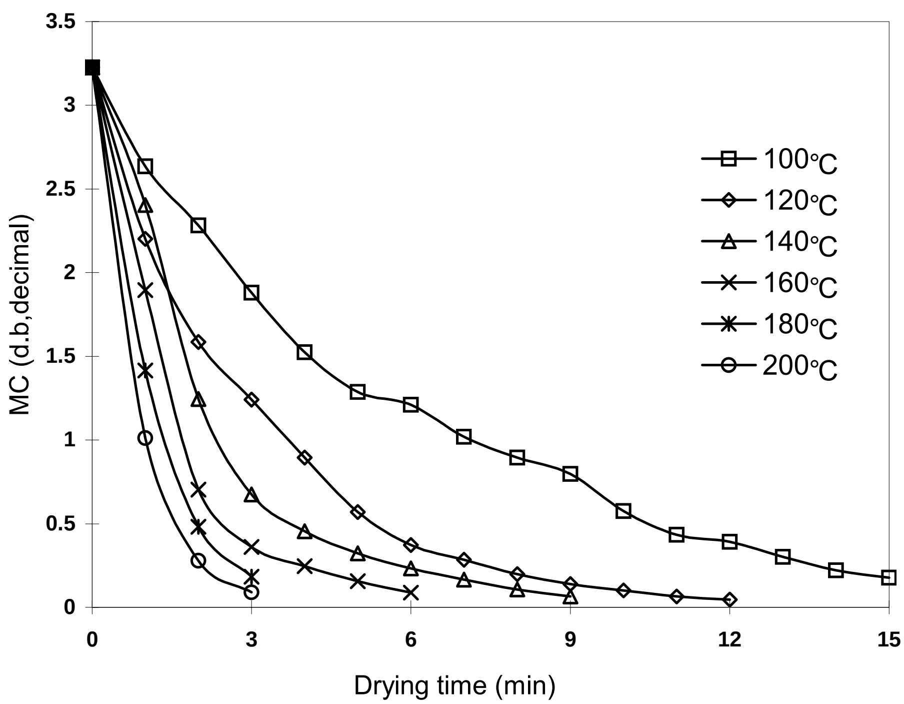
Results and Discussions

Drying characteristics

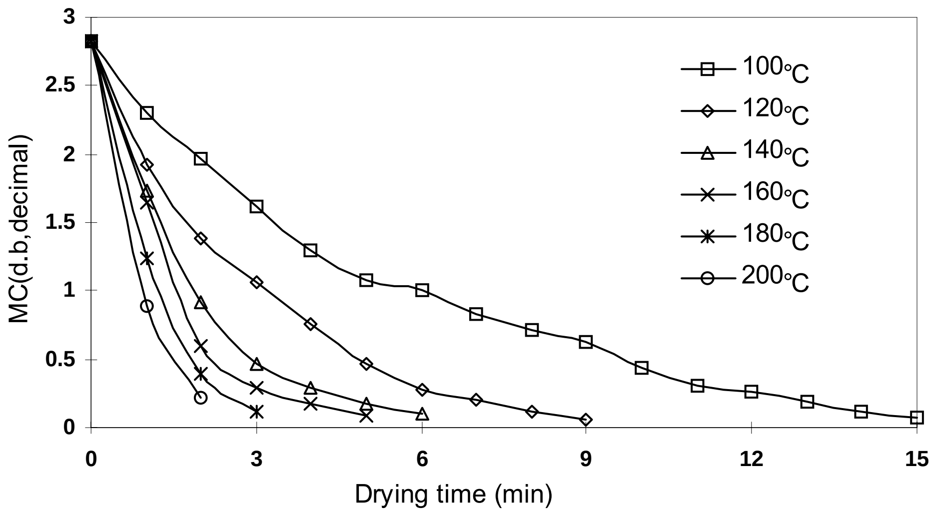
The drying curves of different components showed that their drying rates were different. The drying rates also changed with drying temperatures (Fig. 1). The average drying rates of different components at different temperatures are shown in Fig. 2. It is clear that high drying temperature was corresponded to high drying rate due to the large amount of heat supplied. It was also observed that the average drying rate increase accelerated at the drying temperature above 160°C. The reason caused the acceleration was not known. As expected, crushed stems had consistent high drying rates than the uncrushed stems at different temperatures. When the stems with attached leaves were crushed, the drying rate was similar to or slightly higher than the drying rate of crushed stems. This indicates that leaves on the stems did not significantly affect the stem drying rate.



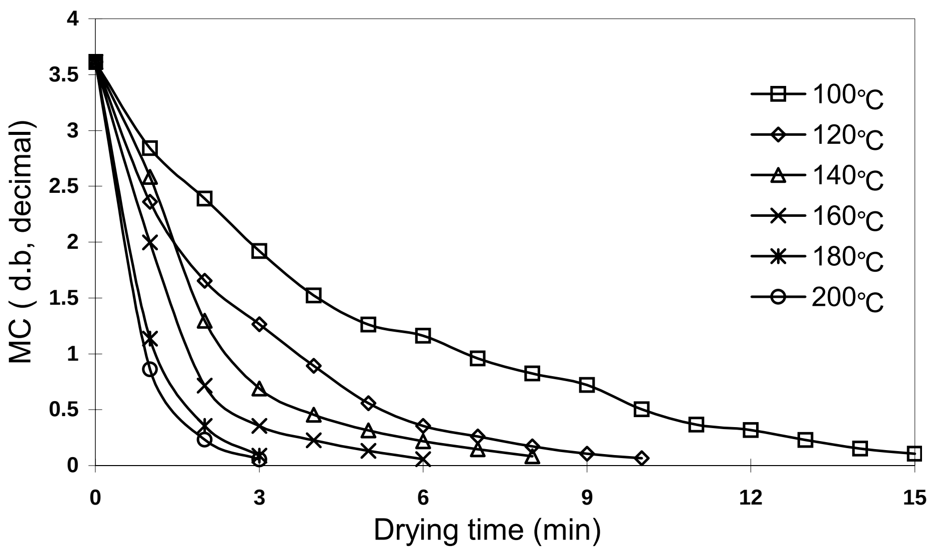
(a) leaves



(b) un-crushed stems



(c) crushed stems



(d) crushed stems with leaves

Figure 1 Moisture contents of different alfalfa components under different drying conditions (air velocity 0.3m/s)

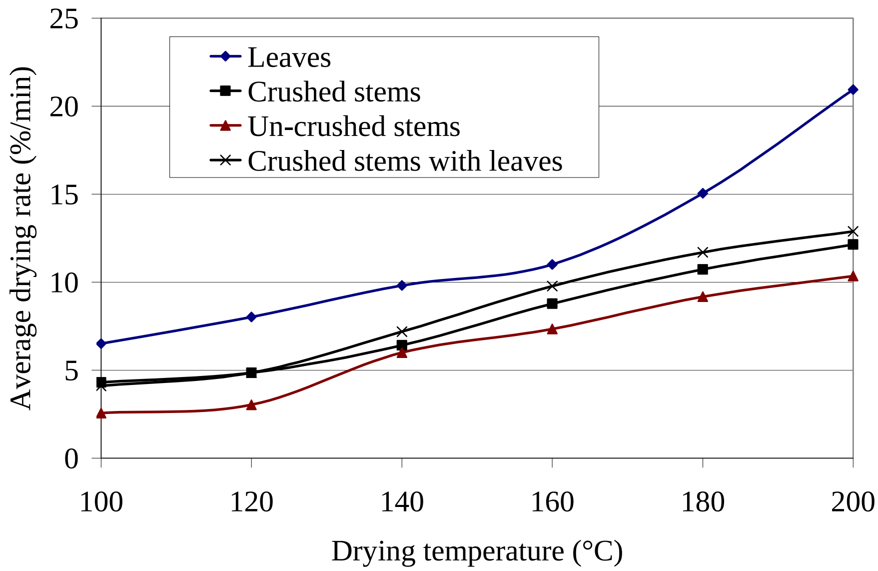


Figure 2 Average drying rates of different alfalfa components under different drying temperatures (air velocity 0.3m/s)

Drying modeling

When the drying data were fitted with the exponential model through regression, the R^2 values were in the range from 0.9045 to 0.9997, which indicate that exponential model is appropriate for describing the drying behaviors. As expected, the drying constant values increased with the increase of drying temperature. The leaves and un-crushed stems had the highest and lowest drying constant values, respectively, among the four components.

The activation energies of different components showed that crushed stems and leaves had the lowest and highest values. The high activation energy of leaves was primarily due to high drying rate at high temperature. Since the activation energy is the amount of energy required to ensure that a reaction happens, at high temperature the probability that two molecules will collide is high. The high collision rate results in a higher kinetic energy, which has an effect on the activation energy of the reaction.

Table 1 Drying constants (min^{-1}) and R^2 values of different components under different drying temperatures

Drying temperature(°C)	Crushed stems with leaves		Un-crushed stems		Crushed stems		Leaves	
	k (min^{-1})	R^2	k (min^{-1})	R^2	k (min^{-1})	R^2	k (min^{-1})	R^2
100	0.1274	0.9052	0.1023	0.9369	0.14	0.8875	0.1554	0.9241
120	0.2510	0.9517	0.2421	0.9586	0.2717	0.9336	0.2051	0.9743
140	0.2886	0.9814	0.2777	0.9701	0.3523	0.9818	0.3234	0.9907
160	0.4420	0.9767	0.3784	0.9876	0.4569	0.9836	0.6441	0.9962
180	0.7531	0.9475	0.5378	0.9934	0.6473	0.9459	1.3538	0.9489
200	0.9056	0.9657	0.7541	0.9882	0.759	0.9566	2.5	0.9997

Table 2 Activation energy Ea (kJ /mol) values of different components

Crushed whole alfalfa plant		Un-crushed stems		Crushed stems		Leaves	
Ea (kJ/mol)	R^2	Ea (kJ/mol)	R^2	Ea (kJ/mol)	R^2	Ea (kJ/mol)	R^2
411	0.9772	387.6	0.9601	346.6	0.9762	606.7	0.9573

Effect of drying conditions on quality

Regardless the velocity of heated air, the protein contents of leaves dried with 180°C and 200°C were apparently lower than the rest of samples. Therefore, to reduce the protein loss caused by the high drying temperature, the drying temperature below 160°C should be used. Drying temperature did not cause significant change in crude fiber in stems.

The required drying time was significantly reduced when the air velocity increased from 0.15 to 0.45 m/s. But the air velocity did not affect the protein and fiber content. Therefore, to reduce drying time, high drying air velocity could be used, even though the high energy consumption associated with high air velocity need to be considered.

When crushed stems with attached leaves were dried to the required final moisture content (12%), the moisture in the stems and leaves were significantly different (Fig. 3). The difference was increased with the increase of drying temperature and air velocity. High drying rates were corresponded to high moisture differences between the stems and leaves. This is due to that the high drying temperature and air velocity resulted in more moisture loss from leaves, which was attached on the out-surface of the stems, than the stems. The Increase of air velocity from 0.15 to 0.45 m/s caused the rise of moisture difference from 1.9% to 4.5%, while increase of the drying temperature from 100°C to 200°C resulted in the moisture difference from 11.3% to 13.9%. This means that drying temperature had more influence on the moisture difference than the air velocity.

Table 3 Drying parameters and compositions of alfalfa forage

Drying temperature (°C)	Air velocity (m/s)	Drying duration (min)	Crude protin in leaves (%)	Crude fiber in stems (%)
100	0.15	15.6	17.26±0.07	22.46±0.09
120	0.15	11.5	18.61±0.09	22.57±0.11
140	0.15	8.7	18.34±0.22	22.46±0.05
160	0.15	6.7	17.77±0.52	22.15±0.26
180	0.15	5.3	16.23±0.34	22.56±0.17
200	0.15	4.4	15.17± 0.56	21.93±0.34
100	0.30	11.3	17.51±0.34	22.35±0.12
120	0.30	8.4	17.93±0.19	22.71±0.18
140	0.30	6.3	18.23±0.26	22.56±0.12
160	0.30	4.9	18.11±0.26	22.38±0.04
180	0.30	3.9	16.52±0.31	23.12±0.51
200	0.30	3.2	15.22±0.60	22.25±0.26
100	0.45	9.5	18.16±0.35	22.31±0.24
120	0.45	7.1	18.11±0.15	22.55±0.22
140	0.45	5.3	17.62±0.22	22.19±0.34
160	0.45	4.1	17.21±0.14	22.65±0.11
180	0.45	3.3	16.32±0.27	22.09±0.20
200	0.45	2.7	15.25±0.28	22.16±0.47

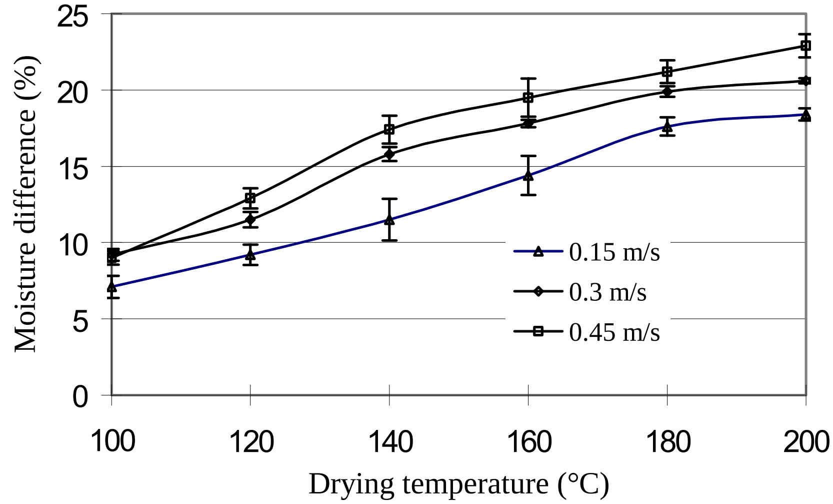


Figure 3 Moisture differences between stems and leaves under different drying conditions

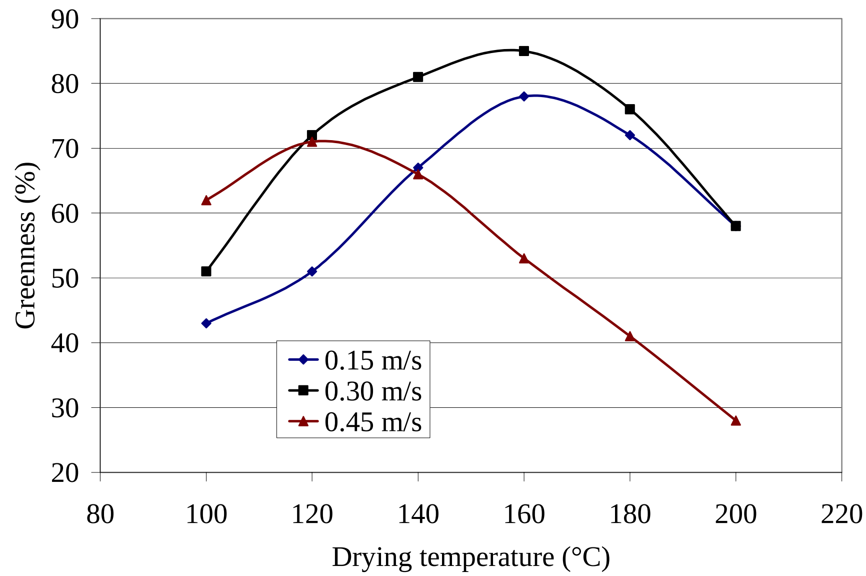


Figure 4 Greenness of alfalfa leaves dried with different air temperatures and velocities

The color change of alfalfa leaves under different drying temperatures and air velocities showed that greenness improved with the increase of air velocity and temperature at low temperature range. This could be due to a high temperature and short time treatment which improved chlorophyll retention (Gupte, 1964). However, the high drying intensity due to the combination of high drying temperature and air velocity resulted in the changed color from fresh greenness to scorched brown. The combination of drying temperature of 160°C and air velocity of 0.30 m/s gave the highest greenness.

Conclusion

Both drying temperature and air velocity had significant effect on drying rate and color of finished products. Modest drying with 160°C temperature and 0.3m/s air velocity gave the best color of the product. The leaves and uncrushed stems showed the highest and lowest drying rates, respectively. Crushing treatment improved the drying rate and reduced the required drying time. The moisture difference between the leaves and stems was significant and increased with the increase of drying temperature and air velocity. Excessive high drying temperature could result in loss of protein in the leaves. But the air velocity did not show significant effect on pro tein and fiber contents.

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